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Relationship of Aerobic Power to Anaerobic Performance Indices

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ABSTRACT

This study examined the extent to which aerobic power could account for performance during a 30-s max-effort test. Physically active women (n = 41) and men (n = 34) underwent a treadmill test for aerobic power and the Wingate test for anaerobic power and fatigue. Pearson product-moment correlation coefficients were calculated from Wingate segments of various durations and temporal positions. For aerobic and anaerobic power, all correlations (positive) in both genders were significant ($p \leq 0.05$) but low, except for those of the first two 5-s segments in the men. For fatigue indices involved in significant negative correlations (all were in the women's group), aerobic power explained only 10 to 19% of the common variance. For anaerobic power there was a trend of stronger correlations from the longer or latter segments. For fatigue, more and stronger relationships were found with the latter segments and with a longer spacing between contrasted segments. This study supports previous evidence for a decreasing role of aerobic power with decreasing duration of a target max-effort performance.

Key Words: cycle ergometer, maximal-effort, men, recreationally trained, Wingate test, women

Introduction

One approach to sport conditioning is to include a general preparatory phase, early in the yearly cycle, that is largely composed of aerobic training (3). Advocates of this system claim it is necessary to establish an aerobic base in order to progress to higher intensity conditioning, not only from a health and safety perspective (23) but also to maximize anaerobic power in all sports (27). According to this training philosophy, higher aerobic power would contribute to higher anaerobic power, albeit the extent of aerobic training should depend on the duration and nature of the sport and the athlete's training status (3, 27). Based on training specificity, the degree of emphasis on aerobic training should coincide with the extent that success in the sport depends on aerobic metabolism. Therefore certain sports would require no specifically *aerobic* training. Nonetheless, an aerobic-base approach is often incorporated even in today's training programs for 100-m sprint runners (28, 31).

Regarding the relationship between aerobic power and anaerobic sport performance, the positive correlations shown previously have not been very strong. This is true even for field tests or sports that have a significant aerobic component, such as middle-distance running events (5, 14). When coaches and elite athletes use this approach in training for sports at the highest end of the intensity continuum, the rationale must be that there is a positive relationship between aerobic fitness and not only lactate-accumulating energy production but also phosphagenic energy production.

The evidence is equivocal for the relationship between aerobic power and performance, not only in shorter tests of up to 2 min (11, 16, 17, 29) but also for longer tests (5, 14, 33). It would seem that there can be no such relationship unless the anaerobic performance, when involving a continuous and maximal effort, is of sufficient duration. Thus the relationship should be examined with anaerobic indices involving test segments of various durations and temporal locations within a longer test.

Häkkinen et al. (12) have examined the latter and found a weaker relationship with power from the 30th to the 45th second of a maximal effort test than with power from the 45th to the 60th sec. They found no relationship with power from 0 to 15 and from 15 to 30 sec; however, Häkkinen et al. (13) did show a low positive correlation as early as 15 to 30 sec. Furthermore, it has been suggested that the relationship should be present when fatigue indices are used (30). Higher aerobic power, by contributing to higher overall power output throughout the test, should contribute to a lower rate of power decline.

Relationships depend on the subjects and on the exact test protocols used. These relationships should be apparent even though it is known that some individuals have both good aerobic and anaerobic capacities, some have one or the other, and some have neither (6). A relationship should also hold regardless of gender. The purpose of this study was to find the extent to which differences in aerobic power in recreationally trained men and women could explain the differences in performance during various phases of a 30-sec all-out test.

Methods

Subjects

Forty-one women and 34 men who were considered recreationally trained volunteered for this study and provided written informed consent. They had not been participating in any high-level or sport-specific conditioning program but, as the testing indicates, had undergone various levels of aerobic training. None had undergone any specifically anaerobic training. The subjects were separated by gender because sociocultural differences between men and women can have an impact on the nature of recreational physical activity in ways that may affect aerobic and anaerobic power. Subject characteristics are shown in Table 1.

Body Composition

Body density in women was estimated from the triceps, suprailiac, and thigh skinfold sites with a Lange caliper (Country Technology, Gays Mills, WI) according to the Jackson and Pollock method (15). A hydrostatic weighing method was used for the men (9, 32). The percent body fat for both genders was estimated using the Siri equation (28). Fat-free mass was estimated from the body mass and body fat percentage value.

Table 1
Subject Characteristics and Performance Results

Variable	Women (n = 41) *M*	*SE*	Men (n = 34) *M*	*SE*
Age (yrs)	20.7	0.4	23.2	0.5
Height (cm)	166.9	0.8	179.2	0.7
Mass (kg)	61.3	1.4	75.2	1.5
Percent fat (%)	25.2	1.0	15.5	0.9
Fat-free mass (kg)	45.4	0.7	63.3	1.1
Peak power (1st 5 s)				
(W)	572.2	17.0	672.5	18.0
($W \cdot kg\ BM^{-1}$)	9.40	0.25	8.99	0.24
($W \cdot kg\ FFM^{-1}$)	12.57	0.31	10.64	0.26
Mean power (30 s)				
(W)	373.1	11.0	445.2	12.2
($W \cdot kg\ BM^{-1}$)	6.14	0.17	5.94	0.15
($W \cdot kg\ FFM^{-1}$)	8.19	0.19	7.03	0.16
Total fatigue (Δ1st–6th 5 s) (%)	52.7	2.0	51.9	1.4
Aerobic power				
($L \cdot min^{-1}$)	2.75	0.06	4.07	0.08
($ml \cdot kg^{-1}$)	45.2	1.0	54.5	0.9

Aerobic Power

A $\dot{V}O_2max$ continuous treadmill test was used to measure aerobic power. Higher $\dot{V}O_2max$ values are obtained with a running test than with other modalities such as cycling or swimming (20, 21, 22). Because it involves more musculature, running demands a greater cardiac output and oxygen uptake. Prior to the test each subject was familiarized with the treadmill (Quinton Instrument Co., Seattle) by warming up with a 54–80 $m \cdot min^{-1}$ walk for 3 to 5 min. The subject then paused, standing, while the breathing apparatus was fitted. To begin the test, we increased the treadmill velocity until the subject signaled that he or she was at a comfortable pace. The test involved consistent grade increases and a constant velocity until volitional fatigue (7). A computerized system with Ametek analyzers was used to measure metabolic data. The system was calibrated before each test. Both absolute $\dot{V}O_2max$ ($L \cdot min^{-1}$) and $\dot{V}O_2$ max relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$) were calculated, but only the results of the latter are the focus of this paper.

Anaerobic Power

The Wingate test (1) was selected because it measures anaerobic performance in units of power, from peak power to mean power. This contrasts with other tests that provide performance in units of time (anaerobic endurance). It is also a popular test among researchers as well as athletes. Furthermore, it offers a fatigue profile because it allows power output to be investigated during various segments of the test duration.

A cycle ergometer (Monark, Varberg, Sweden) was anchored to the floor to ensure stability. Toe stirrups were used, thereby recruiting more muscle mass throughout the movement (19). Seat height was adjusted to allow complete extension of the knee with the ankle flexed at 90°. The subject was asked to give maximal effort throughout the 30-sec test. But first the subject underwent a 2-min warm-up on a cycle ergometer using a self-selected resistance and cadence, followed by 1 min of rest. He or she was then instructed to pedal as fast as possible. When this point was reached, the opposing force ($0.075\ kp \cdot kg$ body $mass^{-1}$) was applied.

The subject remained seated throughout the exercise test. An investigator gave verbal encouragement and time announcements. Pedal revolutions were monitored and recorded at 5-sec intervals until the opposing force was released; the subject continued to pedal with a self-selected resistance and cadence to reduce venous pooling in the legs.

To examine aerobic power relationships with anaerobic power at various phases of the test, mean power output was determined for the full 30 seconds: each of the six 5-sec segments, each of the three 10-sec segments, and both 15-sec segments. These indices were labeled by a code (Table 2) whereby the first number

Table 2
Significant Pearson Correlation Coefficients Between Aerobic Power and Wingate Anaerobic Power or Fatigue

Power output indices	Women	Men	Fatigue indices	Women
1st 5 s (peak)	0.46		Δ1st–2nd 5 s	
2nd 5 s	0.48		Δ1st–3rd 5 s	
3rd 5 s	0.59	0.35	Δ1st–4th 5 s	–0.32
4th 5 s	0.64	0.47	Δ1st–5th 5 s	–0.34
5th 5 s	0.62	0.45	Δ1st–6th 5 s (total)	–0.44
6th 5 s	0.65	0.40	Δ2nd–3rd 5 s	
1st 10 s	0.50	0.34	Δ2nd–4th 5 s	
2nd 10 s	0.66	0.42	Δ2nd–5th 5 s	
3rd 10 s	0.66	0.43	Δ2nd–6th 5 s	–0.37
1st 15 s	0.57	0.36	Δ3rd–4th 5 s	
2nd 15 s	0.68	0.45	Δ3rd–5th 5 s	
30- s (total)	0.68	0.42	Δ3rd–6th 5 s	–0.35
			Δ4th–5th 5 s	
			Δ4th–6th 5 s	–0.34
			Δ5th–6th 5 s	–0.40
			Δ1st–2nd 10 s	
			Δ1st–3rd 10 s	–0.40
			Δ2nd–3rd 10 s	–0.35
			Δ1st–2nd 15 s	–0.39

identified the temporal position of the segment and the second number identified its duration. In addition to absolute values, power was also calculated relative to body mass and fat-free mass.

Fatigue was also calculated from the Wingate test. This was the change in power output between two segments of similar duration, expressed as a percentage of the power output of the earlier segment. In the coding, the two numbers that are separated by the hyphen identify the temporal position of the involved segments. The duration of the segments is again identified by the final number.

Included in these power scores are three popular indices; peak power, total power, and total fatigue. Peak power, determined as the highest 5-sec segment average power output, always occurred during the first segment (1st 5 sec). Mean power (2) was computed using the total revolutions for the full 30 sec of the test. Total fatigue is the percentage of power lost from the first (peak power) to the sixth (lowest power) 5-sec segment (Δ 1st to 6th 5 sec). Total fatigue has also been called simply "percent fatigue" in studies in which the various other segment combinations were not examined (2).

Statistical Analysis

A Pearson product-moment correlation coefficient was calculated ($p \leq 0.05$) between aerobic power and each Wingate anaerobic power and fatigue variable for the men and for the women.

Results

Subject characteristics and the major Wingate indices are listed in Table 1. The correlation coefficients involving aerobic power and the Wingate anaerobic power variables, all relative to body mass, are shown in Table 2. All of the women's correlations were significant. In the men all of the power output variables were involved in significant correlations except for the 1st 5 sec (peak power) and 2nd 5 sec. All coefficients involving Wingate anaerobic power were positive.

The only significant relationships between the Wingate fatigue variables and aerobic power occurred in the women's group. These negative correlation coefficients involved Δ 1st–4th 5 sec, Δ 1st–5th 5 sec, Δ 1st–6th 5 sec (total fatigue), Δ 2nd–6th 5 sec, Δ 3rd–6th 5 sec, Δ 4th–6th 5 sec, Δ 5th–6th 5 sec, Δ 1st–3rd 10 sec, Δ 2nd–3rd 10 sec, and Δ 1st–2nd 15 sec.

Discussion

Relationships can be shown among many fitness variables, including aerobic and anaerobic components, simply based on body mass. Significant correlations can be lost if body mass is not accounted for. Body mass has been shown to explain between 44 and 83% of the power output variance in a 30-sec Wingate test (24, 29), and up to 50% of the variance in a 2-min maximal-effort cycle ergometer test (17). True relationships, though, should be sustained even after the results are normalized for body mass. To avoid the effect of body mass in this study, we used results relative to body mass in both aerobic and anaerobic power.

The contribution of the aerobic energy system increases with the increasing duration of anaerobic power and anaerobic capacity tests. Oxidative metabolism has been shown to contribute only 3% of the energy produced in a 10-sec test, and 9 to 28% in a 30-sec test (2, 18, 26). Higher values of 46 to 50% have been shown for longer bouts of 60 and 90 sec (10, 26). In keeping with this pattern, we expected more and stronger correlations from the latter parts of the Wingate test.

Some of our results support this pattern. There was a trend of stronger positive relationships with increasing duration of Wingate test segments (i.e., from 1st 5 sec to 1st 10 sec to 1st 15 sec to 30 sec). Also, the groups showed a trend of stronger positive relationships for subsequent segments of similar duration (from 1st 15 sec to 2nd 15 sec, from 1st 10 sec to 2nd 10 sec, and from 1st 5 sec to 2nd 5 sec to 3rd 5 sec to 4th 5 sec). It is unclear why the pattern did not continue into the latter 5-sec stages or the final 10-sec stage of the 30-sec test.

The significant correlations for the women accounted for 34 to 46% of the common variance. The men had correlations accounting for 12 to 22% of the common variance. Additional comparisons to previous studies can be made with the correlations between power output variables and aerobic power. Our coefficient of common variance involving the 1st 10 sec was 25% and 12% for the women and men, respectively. These values are lower than the 56% obtained for sedentary men and women combined (4). The same study produced a value of 61% for the 6th 5 sec compared to our 42% and 16% values for women and men, respectively. A portion of the higher values in Boulay et al. (4) may be due to the aerobic power test being performed on a cycle ergometer rather than on a treadmill.

Häkkinen et al. (13), using a group of powerlifters, bodybuilders, and wrestlers, found no relationship for the 1st 15 sec, and $r = 0.65$ for the 2nd 15 sec. A subsequent study (12) on elite weightlifters showed no relationship for either the 1st or 2nd 15 sec. The men's results in the present study are not very different because the correlations of $r = 0.36$ and 0.45 for the 1st and 2nd 15 sec, respectively, are very low. For the full 30 sec (total power), the low correlations in the present study are lower than the coefficient of $r = 0.87$ obtained by Jaskólski et al. (16) in male middle-distance runners. Alternatively, some studies have shown a lack of correlation between 30-sec power and aerobic power (17, 29).

No studies could be identified that looked for a relationship between fatigue indices and aerobic power. In view of the overall picture provided by the results of the present study, an argument can be made for a pattern suggesting an oxidative mechanism that gradually gains importance. Specifically, more and stronger relationships tended to occur when the fatigue variable involved a segment from the latter part of the Wingate test and a longer spacing between contrasted segments. Nonetheless, aerobic power explained only 10 to 19% of the respective common variance of fatigue variables that were involved in significant negative correlations; all were found in the women.

Other than the fact that a specific gender is involved, certain differences in aerobic power may be considered. Among recreationally trained individuals, a lower aerobic power (as in the women) suggests a lower overall physical training status. It is more likely that the aerobic and anaerobic characteristics will be parallel when there is no high-level specific training, which means that the person's physical fitness level is largely determined, beyond genetics, by the amount of physical activity characterizing his or her recreation and lifestyle.

When sedentary or untrained subjects have been used, positive but low/moderate correlations have been shown even for aerobic power with 1-sec peak pedaling power ($r = 0.63$) (4) or with a modified Margaria stair-climb test, which usually lasts less than 1 sec (25). It should be obvious that aerobic power was not at all responsible for performance in these very brief and highly anaerobic tests. Conversely, a higher aerobic power (as in the men's group) might reflect a greater level of aerobic conditioning without a concomitantly greater level of anaerobic training. Although the $\dot{V}O_2max$ per kilogram of body mass for the men can be considered to be a recreational caliber, according to Brandon and Boileau (5), this higher aerobic power may have helped to disengage the aerobic and anaerobic characteristics. This may partially explain some of this study's results.

The following contrasts between the men and women are made in light of a similar dispersion of aerobic power values relative to body mass in these two groups. When aerobic power and fatigue variables were involved, 10 significant negative correlations were found in the women (lower aerobic power); none were found in the men (higher aerobic power). Concerning the 1st (peak power) or 2nd 5 sec, significant but low positive correlations ($r^2 = 21$ to 23%) were shown with aerobic power for women but not for men.

In support of this, others have found no relationship between aerobic power and peak anaerobic power in a group of untrained male students (8) who had aerobic power similar to our male subjects, or in healthy men (17) with higher aerobic power than our subjects, or in male judokas (29). A very strong relationship ($r = 0.95$) has been shown in middle-distance runners (16), probably due to the mixed nature of the type of training involved.

Also, Crielaard and Pirnay (8) showed an inverse relationship ($r = -0.83$) for aerobic power and peak power in a group of elite athletes: sprinters and middle- and long-distance runners. All correlations involving Wingate anaerobic power variables, even peak power, were positive. All correlations involving fatigue variables were negative. This is expected if aerobic power is thought to aid, even minimally, performance on the Wingate test. Conversely, positive correlations involving fatigue indices or negative correlations involving anaerobic power output indices may be thought to indicate high-level and very exclusive aerobic or anaerobic training. In addition to homogeneous training, they may also be attributed to the extreme nature of the phenotypic selection of elite athletes at the ends of the sport-duration continuum.

Practical Applications

It is obvious that one should train aerobically when preparing for a performance that is aerobic in nature. In sprint activities involving a maximal effort for 30 sec or less (characterized as anaerobic), aerobic power is used only to a small extent. The relationships found in this and other cross-sectional studies, as well as data from metabolic characterization studies, need to be corroborated with a training study before recommendations can be made with certainty.

Evidence thus far suggests that unless the sport involves an event lasting 15 sec or more, or involves repeated efforts of shorter duration without adequate recovery (e.g., football, hockey, wrestling), improving aerobic power would not be a highly effective way to improve performance. Also, such findings, and subsequent training advice, may vary depending on the caliber of the athlete.

Even when the relationship with aerobic power in sprint performance justifies aerobic power as a training goal, the low correlations would lead us to hypothesize that this goal can contribute only marginally to performance. Interval training may be a better way to accomplish this goal while still emphasizing the sprint qualities of the sport. Instead of undertaking long, continuous exercise, one can therefore practice a form of sport specificity. Also, based on metabolic characterization studies and in the absence of training studies, the shorter the target maximal-effort performance is, from 30 sec down to 10 or 15 sec, the more that distance training can be de-emphasized. Finally, whenever recommendations are made to minimize or exclude aerobic training in certain situations, they do not account for the potentially beneficial role of aerobic exercise in general health and physical fitness.

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Notes

Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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